

Electronic Imaging Impact on Image and Report Turnaround Times

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We prospectively compared image and report delivery times in our Urgent Care Center (UCC) during a film-based practice (1995) and after complete implementation of an electronic imaging practice in 1997. Before switching to a totally electronic and filmless practice, multiple time periods were consistently measured during a 1-week period in May 1995 and then again in a similar week in May 1997 after implementation of electronic imaging. All practice patterns were the same except for a film-based practice in 1995 versus a filmless practice in 1997. The following times were measured: (1) waiting room time, (2) technologist's time of examination, (3) time to quality control, (4) radiology interpretation times, (5) radiology image and report delivery time, (6) total radiology turnaround time, (7) time to room the patient back in the UCC, and (8) time until the ordering physician views the film. Waiting room time was longer in 1997 (average time, 26:47) versus 1995 (average time, 15:54). The technologist's examination completion time was approximately the same (1995 average time, 06:12; 1997 average time, 05:41). There was also a slight increase in the time of the technologist's electronic verification or quality control in 1997 (average time, 7:17) versus the film-based practice in 1995 (average time, 2:35). However, radiology interpretation times dramatically improved (average time, 49:38 in 1995 versus average time 13:50 in 1997). There was also a decrease in image delivery times to the clinicians in 1997 (median, 53 minutes) versus the film based practice of 1995 (1 hour and 40 minutes). Reports were available with the images immediately upon completion by the radiologist in 1997, compared with a median time of 27 minutes in 1995. Importantly, patients were roomed back into the UCC examination rooms faster after the radiologic procedure in 1997 (average time, 13:36) than they were in 1995 (29:38). Finally, the ordering physicians viewed the diagnostic images and reports in dramatically less time in 1997 (median, 26 minutes) versus 1995 (median, 1 hour and 5 minutes). In conclusion, a filmless electronic imaging practice within our UCC greatly improved radiology image and report delivery times, as well as improved clinical efficiency.

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COMPUTED RADIOGRAPHY (CR) and picture archiving and communication systems (PACS) are rapidly replacing conventional film/screen practices in radiology departments. Previous attempts to demonstrate improved efficiency with such electronic imaging have produced variable

Table 1. Information Requested

Requesting physician	Compare films required (Y/N)
Patient identification number	Time stopped reading
Location of requesting desk	Time restarted reading with compare films
Time x-ray requested	Radiologist completes case
If results were requested for same day	Report pasting complete
If comparison was requested	Film received by UCC
No. of films	Physician reviewing film
Time exam began (pt. entered room)	Time physician views image or report
Time exam completed (pt. left room)	Consult with radiologist (Y/N)
Film retake (Y/N)	Time patient returned from x-ray
Image verified by Quality Control (pt. released)	Time patient roomed after x-ray
Radiologist begins case	Time physician enters after x-ray

results.¹⁻⁶ Although the technology continues to evolve, its clinical use has been well documented.⁷⁻¹⁰ It is intuitive that such a practice would be more efficient. However, there is no evidence to support this in the ambulatory care setting. To support widespread implementation of electronic imaging into the outpatient setting, as well as the inpatient setting, we attempted to provide such evidence.

MATERIALS AND METHODS

Selection of Patients

We conducted a prospective trial enrolling consecutive patients seen in the Urgent Care Center (UCC) at our institution who received a radiologic examination. The UCC is a no-appointment ambulatory care practice for patients of all ages. Patients were enrolled during two time periods. The first group of consecutive patients were seen in the UCC from Saturday, May 13, 1995 to Friday May 19, 1995. During this period, a conventional film/screen system was used to perform the radiologic examinations. The second group of patients were

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enrolled from Saturday May 17, 1997 to Saturday May 24, 1997. During this period, all examinations were performed and delivered electronically.

All radiologic examinations fit into one of two types. Extremity examinations (EXT) included any examination of the shoulder or distal upper extremity, as well as any examination of the hips or any distal lower extremity. The other type was chest

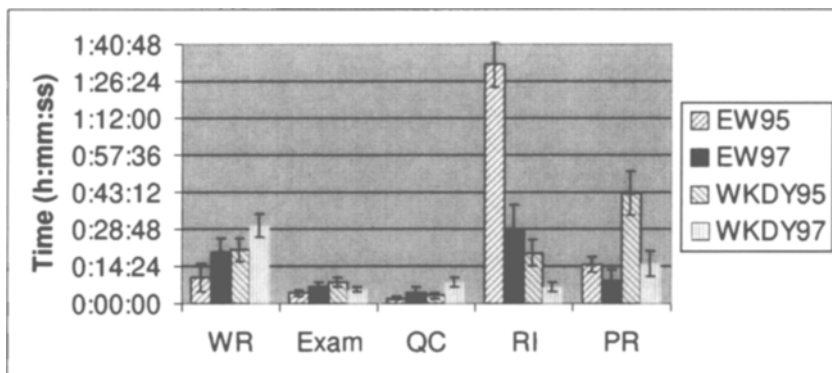
x-rays (CXR), including chest x-rays, sinus, or rib films. The former type of examination was intended to represent primarily posttraumatic complaints, while the latter complaints of a more inflammatory nature. A total of 215 patients were entered into our study. Two patients received two examinations, for a total of 217 radiologic examinations performed during the collection periods.

Table 2. Times by Category

	Categories							
	WR	Exam	QC	RI	IR	RT	PR	PV
EW95EXT								
n	29	29	28	25	20	23	19	22
Mean	0:11:50	0:04:36	0:01:46	1:29:59	5:13:52	7:52:26	0:13:09	5:28:49
SE	0:04:16	0:00:49	0:00:17	0:05:29	1:38:46	1:31:52	0:01:23	1:24:46
Median	0:06:00	0:04:00	0:02:00	1:40:00	0:41:30	2:54:00	0:13:00	2:10:30
95% CI +/-	0:08:45	0:01:40	0:00:35	0:11:19	3:26:43	3:10:31	0:02:54	2:56:17
EW95CXR								
n	19	19	18	16	10	12	9	13
Mean	0:07:09	0:03:03	0:02:20	1:37:37	8:40:36	10:47:45	0:19:00	6:30:42
SE	0:01:12	0:00:36	0:00:33	0:07:23	2:21:09	1:58:24	0:02:52	1:52:43
Median	0:06:00	0:02:00	0:02:00	1:36:30	11:28:00	12:36:30	0:19:00	2:35:00
95% CI +/-	0:02:31	0:01:16	0:01:09	0:15:45	5:19:19	4:20:36	0:06:37	4:05:36
EW97EXT								
n	18	21	14	13	22	17	7	10
Mean	0:21:43	0:06:57	0:05:43	0:27:18	0:00:00	1:01:42	0:06:43	0:34:12
SE	0:03:25	0:00:53	0:01:21	0:06:31	0:00:00	0:08:14	0:01:58	0:07:47
Median	0:16:00	0:06:00	0:04:30	0:19:00	0:00:00	0:54:00	0:05:00	0:26:00
95% CI +/-	0:07:12	0:01:50	0:02:55	0:14:11	0:00:00	0:17:28	0:04:48	0:17:37
EW97CXR								
n	10	12	8	8	12	10	2	8
Mean	0:16:42	0:05:30	0:01:23	0:29:52	0:00:00	0:55:30	0:15:00	0:26:00
SE	0:03:25	0:01:34	0:00:28	0:07:30	0:00:00	0:07:54	0:02:00	0:07:54
Median	0:13:30	0:02:30	0:01:30	0:26:30	0:00:00	0:53:00	0:15:00	0:17:30
95% CI +/-	0:07:43	0:03:26	0:01:05	0:17:43	0:00:00	0:17	0:25:25	0:18:40
WKDY95EXT								
n	44	43	42	44	41	41	26	31
Mean	0:21:07	0:08:11	0:03:14	0:20:08	0:21:59	1:13:51	0:37:12	1:20:48
SE	0:02:46	0:00:49	0:00:41	0:03:21	0:01:24	0:05:21	0:03:27	0:28:43
Median	0:20:00	0:07:00	0:03:00	0:11:35	0:22:50	1:05:00	0:34:30	0:45:00
95% CI +/-	0:05:34	0:01:39	0:01:24	0:06:46	0:02:49	0:10:50	0:07:06	0:58:38
WKDY95CXR								
n	15	15	15	15	9	9	5	9
Mean	0:19:32	0:07:36	0:02:32	0:17:44	0:22:28	1:06:07	1:12:00	0:58:13
SE	0:03:30	0:02:40	0:00:34	0:03:43	0:04:57	0:08:32	0:13:19	0:07:34
Median	0:15:00	0:03:00	0:02:00	0:15:00	0:18:55	1:05:00	1:09:00	1:05:00
95% CI +/-	0:07:30	0:05:42	0:01:13	0:07:59	0:11:24	0:19:40	0:36:58	0:17:28
WKDY97EXT								
n	34	41	41	23	44	18	19	38
Mean	0:30:55	0:06:19	0:09:47	0:06:29	0:00:00	0:57:00	0:12:35	0:37:16
SE	0:02:53	0:00:43	0:01:24	0:01:04	0:00:00	0:05:15	0:02:35	0:04:01
Median	0:26:00	0:05:00	0:08:00	0:04:00	0:00:00	0:54:30	0:09:00	0:30:00
95% CI +/-	0:05:51	0:01:27	0:02:50	0:02:13	0:00:00	0:11:04	0:05:25	0:08:07
WKDY97CXR								
n	23	31	29	17	31	12	7	17
Mean	0:29:00	0:04:04	0:06:08	0:05:56	0:00:00	0:42:50	0:22:51	0:30:42
SE	0:03:52	0:00:45	0:00:49	0:01:18	0:00:00	0:06:09	0:04:54	0:06:18
Median	0:24:00	0:02:00	0:05:00	0:04:00	0:00:00	0:37:00	0:20:00	0:22:00
95% CI +/-	0:08:01	0:01:32	0:01:40	0:02:46	0:00:00	0:13:31	0:12:00	0:13:22

Abbreviations: SE, standard error, CI, confidence interval.

Fig 1. 1995 v 1997 by time period. Error bars represent 95% confidence intervals.



Patients were further subgrouped as to the time and day of their examination. The first subgroup (WKDY) included those patients whose examinations were performed during regular weekday hours (8 AM to 5 PM). The remaining patients were placed in the evening and weekend (EW) subgroup.

Demographics

There were no statistical differences in age or sex between those patients who participated in 1995 and those of 1997. One hundred eight patients were enrolled in 1995 at a mean age of 37.3 years, as compared with an average age of 35.8 years for the 109 patients enrolled in 1997. The time of year was constant during both time periods to avoid disease-specific bias associated with varying times of the year (eg, upper respiratory disease in February and trauma-related disorders in July). The details are published elsewhere.¹¹

Equipment

Film images were obtained for the 1995 group using conventional screen/film technique appropriate for the body part imaged. During regular hours, films were carried to the staff radiologist in the reading room located immediately adjacent to the x-ray acquisition area. The radiologist would dictate directly to a transcriptionist, and the typed report would be pasted on the examination jacket containing the films. Films would be carried to the UCC approximately every 30 minutes. On evenings and weekends, the film was transported via an automatic transport vehicle to the hospital three blocks away where a resident would interpret the films, paste the interpretation on the jacket, and send the examination back via the automatic transport vehicle.

In some cases, clinicians did walk to the radiology department to view images before they were sent to the hospital for interpretation.

The digital images for the 1997 group were obtained using a Fuji FCR-9000 (Fuji USA, Stamford CT) CR system, except for CXRs, which were obtained with a Fuji FCR-9501 dedicated chest CR unit. Images were then transferred to the PACS (formerly Loral, now General Electrical Medical Systems, Milwaukee, WI), where quality assurance and interpretation were performed by the lead technologist. Following verification, images were immediately available on a PACS workstation in the UCC. In both study groups, radiology reports were immediately transcribed via direct dictation to a transcriptionist.

Time Measurements

Two cards were attached to the patient's file when the patient initially registered at the UCC. These cards were used to record the various times listed in Table 1. Individuals from the Radiology Department and the Department of Systems and Procedures were stationed along the path of the patient (card #1), as well as the path of the x-ray film or image (card #2) throughout the course of the patient visit. In addition, during the 1997 collection period, an observer recorded the use of the PACS viewing station within the UCC on a third card, including the time the ordering physician viewed the image and the report.

From these data the following time periods were calculated:

1. (WR) Waiting room time, from the request of the radiologic exam until the examination began.
2. (Exam) Technologist's time of examination, from the beginning to the end of the examination.

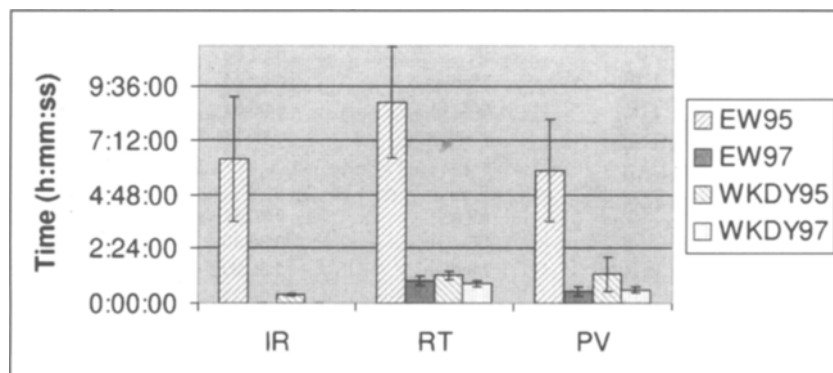


Fig 2. 1995 v 1997 by time period. Error bars represent 95% confidence intervals.

3. (QC) Time to quality control, from the completion of the radiologic exam to the time the examination was verified by the lead technologist. After verification, the examination was placed in the reading room (1995) or was electronically available (1997) for radiologist interpretation.
4. (RI) Radiology interpretation times, from the time the image was verified by quality control until the radiologist had completed the report.
5. (IR) Image/report delivery time, from the completion of the radiology interpretation to the time the image/report were delivered to the UCC.
6. (RT) Radiology turnaround time, from the request of the radiologic examination until the UCC received the film/report (hard copy in 1995, soft copy in 1997).
7. (PR) Time to room the patient back in the UCC, from the time the image was verified and the patient was released from radiology until the patient was placed back into a room in the UCC.
8. (PV) Time until the ordering physician views the film, from the time the image was verified (image available in 1997) until the ordering physician viewed the image and/or report.

Average times were calculated for each time period in each of eight categories (Table 2). The categories were then combined to compare EW patients of 1995 to those of 1997 (Figs 1 and 2). We looked at WKDY patients similarly (Figs 1 and 2). Finally, we compared all patients for 1995 and 1997 (Table 3).

Statistical Analysis

Descriptive analyses were performed for all time periods to provide means (average times), standard error (SE), medians, and 95% confidence intervals. A two-sample student's *t* test assuming equal variances (homoscedastic *t* test) was used to compare the WR, Exam, QC, RI, IR, and PR measurements from 1995 with 1997. Comparisons were made between EW95 and EW97, WKDY95 and WKDY97, and all patients 1995 and 1997. A two-sample student's *t* test assuming unequal variances (heteroscedastic *t* test) was used to compare the RT and PV measurements between 1995 and 1997 in the same groups and subgroups. The latter two time periods demonstrated unequal variances in the initial analyses.

RESULTS

The complete measurements are summarized in Table 2. We noted an increase in radiology waiting room (WR) time in 1997 as compared with 1995 (increase in 11 minutes [mean]), as well as an increase in technologist verification time (QC) in 1997 (increase of 4 minutes and 42 seconds). The increase in WR time was likely due to a dramatic increase in WR patients secondary to an increase in phlebotomy and EKG studies serviced by the same WR. There was no statistical difference in the Exam time from 1995 to 1997. The delays in WR and QC times in 1997 were offset by a dramatic decrease in time in the RI, IR, RT, PR, and PV times. Radiology interpretation (RI) times were

Table 3. All Patients Studied 1995 and 1997

	1995	1997
WR		
n	107	85
Mean	0:15:54	0:26:47
SE	0:01:46	0:01:49
Median	0:10:00	0:23:00
95% CI +/-	0:03:31	0:03:37
P value	3.50E-5	
Exam		
n	106	105
Mean	0:06:12	0:05:41
SE	0:00:35	0:00:27
Median	0:04:00	0:04:00
95% CI +/-	0:01:10	0:00:53
P value	0.482	
QC		
n	103	92
Mean	0:02:35	0:07:17
SE	0:00:19	0:00:45
Median	0:02:00	0:06:00
95% CI +/-	0:00:38	0:01:29
P value	1.03E-08	
RI		
n	100	61
Mean	0:49:38	0:13:50
SE	0:04:20	0:02:11
Median	0:37:05	0:07:00
95% CI +/-	0:08:37	0:04:23
P value	5.94E-09	
IR		
n	80	109
Mean	2:37:20	0:00:00
SE	0:36:05	0:00:00
Median	0:27:25	0:00:00
95% CI +/-	1:11:50	0:00:00
P value	8.51E-07	
RT		
n	85	57
Mean	4:21:54	0:55:09
SE	0:38:51	0:03:33
Median	1:40:00	0:53:00
95% CI +/-	1:17:15	0:07:06
P value	8.98E-07	
PR		
n	59	35
Mean	0:29:38	0:13:36
SE	0:02:55	0:01:56
Median	0:22:00	0:12:00
95% CI +/-	0:05:51	0:03:55
P value	0.000162	
PV		
n	75	73
Mean	3:24:34	0:34:05
SE	0:36:50	0:02:52
Median	1:05:00	0:26:00
95% CI +/-	1:13:24	0:05:44
P value	1.60E-05	

much faster in 1997, completed on average in less than 30% of the time used in 1995. Patients were also roomed faster (PR), with an average savings of over 15 minutes per patient. Upon completion by the radiologist, reports were immediately available with the images. This eliminated the 27 minutes (median time) for image/report delivery (IR) in 1995. One of the most significant time reductions was in the clinical physician's viewing time (PV). The difference in the averages was nearly 3 hours faster with the electronic imaging practice in 1997 compared with the conventional film/screen methods in 1995. This was in large part due to faster RI (radiology interpretation) times and instantaneous IR (image/report turnaround) times in 1997.

Comparative analyses for the EW and WKDY are shown graphically in Figs 1 and 2. In the WKDY subgroup, there were again delays in the WR and QC times in 1997. However, the Exam time was reduced in 1997 for this group. Although the reduction in RI time was less dramatic, the time to room the patient in the UCC after the radiology exam (PR), was nearly 30 minutes less with the CR/PACS practice in 1997 than with the conventional practice in 1995. In this subgroup there was also a reduction in radiology turnaround (RT) time in 1997, but there was no significant difference in PV time. The EW subgroups also demonstrated an increase in WR, Exam, and QC times in 1997. The

patient was roomed (PR) back in the UCC in 1997 in nearly half the time as in 1995. Additionally, there were very significant reductions in IR, RT, and PV times using the electronic imaging equipment in 1997 (Fig 2).

DISCUSSION

The most impressive results from this study are the marked improvement of the time the ordering physician viewed the images/report (PV) in 1997 and the time the patient was roomed back into the UCC (PR) in 1997. The marked improvements of time indicate a major positive impact of electronic imaging on clinical practice in our UCC. These improvements were primarily due to dramatic improvements of radiology interpretation times (RI) and image/report delivery times (IR) in 1997.

Previous studies had shown similar results, but were limited to a medical intensive care unit in the hospital setting.^{3,4} Our results indicate that electronic imaging can also have a positive impact on an outpatient clinical practice.

CONCLUSION

Electronic imaging can dramatically improve radiology interpretation and image/report delivery times, which can facilitate improved efficiency of clinical practice.

REFERENCES

1. Bryan S, Weatherburn G, Watkins J, et al: Radiology report times: Impact of picture archiving and communication systems. *Am J Roentgenol* 170:1153-1159, 1998
2. Kundel HL, Seshadri SB, Langlotz CP, et al: Prospective study of a PACS: Information flow and clinical action in a medical intensive care unit. *Radiology* 199:143-149, 1996
3. Kundel HL, Seshadri SB, Arenson RL: Clinical experience at the University of Pennsylvania. *Comput Med Imaging Graph* 15:197-200, 1991
4. De Simone DN, Kundel HL, Arenson RL, et al: Effect of a digital imaging network on physician behavior in an intensive care unit. *Radiology* 169:41-44, 1988
5. Kato H, Kubota G, Kojima K, et al: Preliminary time-flow study: Comparison of interpretation times between PACS workstations and films. *Comput Med Imaging Graph* 19:261-265, 1995
6. Krupinski EA, Lund PJ: Differences in time to interpretation for evaluation of bone radiographs with monitor and film viewing. *Acad Radiol* 4:177-182, 1997
7. Piraino DW, Davros WJ, Lieber M, et al: Direct digital versus conventional film screen radiography of the musculoskeletal system. *J Digit Imaging* 11:172-173, 1998
8. Procacci C, Minniti S, Biondetti PP, et al: Comparison between conventional radiography and thoravision in the study of the normal chest. *J Digit Imaging* 10:183-184, 1997
9. Kundel HL, Gefter W, Aronchick J, et al: Accuracy of bedside chest hard-copy screen-film versus hard- and soft-copy computed radiographs in a medical intensive care unit: Receiver operating characteristic analysis. *Radiology* 205:859-863, 1997
10. Steckel RJ, Batra P, Johson S, et al: Comparison of hard- and soft-copy digital chest images with different matrix sizes for managing coronary care unit patients. *Am J Roentgenol* 164:837-841, 1995
11. Mattern CWT, Erickson BJ, King BF Jr, et al: Impact of electronic imaging on clinician behavior in the urgent care setting. *J Digit Imaging* 12:148-151, 1999 (suppl 1)